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SMART IOT NAVIGATION SYSTEM FOR VISUALLY IMPAIRED INDIVIDUALS: IMPROVING SAFETY AND INDEPENDENCE WITH ADVANCED OBSTACLE DETECTION

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Abstract:

Visually impaired individuals often face significant challenges in their daily lives, frequently relying on others for assistance and feeling less confident in unfamiliar environments. This paper presents an innovative IoT-based system designed to address these issues by aiding in obstacle and water puddle detection. The system comprises a walking stick integrated with an ESP32 microcontroller, an ultrasound sensor, and a smart phone application. The walking stick collects environmental data through the ultrasound sensor, which the ESP32 processes to identify obstacles. Communication between the microcontroller and the smart phone is facilitated via MIT App Inventor, enabling the app to deliver audible navigation instructions to users. The developed system demonstrated impressive performance, achieving an accuracy of 99.54% at a distance of 250 cm and 99.03% at 450cm. Additionally, it successfully detected obstacles at an angular position of up to 90 degrees. These results highlight the system effectiveness and efficiency in providing precise voice instructions, which are crucial for enhancing navigation for visually impaired individuals. By offering real-time feedback and detailed guidance, this system significantly improves the independence and safety of visually impaired users, boosting their confidence in navigating unfamiliar environments. Overall, the IoT-based navigation system represents a substantial advancement in assistive technology, promising a safer and more autonomous life for those with visual impairments.

Key Words: IoT, assistive technology, visually impaired, obstacle detection, ESP32

Introduction:

Visually impaired individuals, whether partially sighted or completely blind, face numerous challenges in their daily lives. Vision is crucial for processing environmental information, and its absence makes independent travel and exploration difficult. Consequently, many visually impaired people rely on friends, family, or guide dogs for assistance. Blindness results from a disruption in physiological and neurological functions, leading to a state of unconsciousness. However, advancements in modern science and technology offer solutions to ease their struggles and enhance their independence. The World Health Organization (WHO) estimates that around 36 million people worldwide are completely blind, and 217 million have moderate to severe vision impairments. The majority of those with visual impairments are over 50 years old, with a smaller proportion under 15 years old. Recent statistics indicate that the number of visually impaired individuals is expected to rise due to population growth and aging. Typically, visually impaired people rely on white canes or guide dogs for daily activities.

However, white canes have limitations in providing tactile information because of their size, and guide dogs cannot always accurately convey information about dangerous situations, such as road humps. Numerous technological innovations have been developed to enhance the quality of life for visually impaired individuals. These electronic travel aids often utilize sensors and actuators, computer vision, deep learning, and machine learning to facilitate interaction with the environment. Devices equipped with sensors or cameras gather information about the surroundings, which is then communicated to the user. Camera-based obstacle detection technology, for instance, works by capturing images and processing them using computer vision techniques to identify potential hazards.

The devices proposed in this study may not be visually appealing, but the focus is on developing an Internet of Things (IoT) system using a smart phone module to detect obstacles and water puddles. This system combines hardware and software to identify both static and moving obstacles. It integrates an ESP32 microcontroller and an HC-SR04 PIR sensor. The sensors collect environmental data, which the ESP32 microcontroller processes to detect obstacles. Communication between the ESP32 microcontroller and the smart phone is facilitated through the MIT App Inventor. This IoT-based system enhances navigation for visually impaired individuals by making it more convenient to detect obstacles and water puddles.

Related Work:

Extensive research has been conducted to aid visually impaired individuals in navigation. Traditionally, many visually impaired people have relied on guide dogs and white canes for assistance, but these tools have certain limitations. The white cane is the most affordable aid, yet it cannot accurately detect obstacles, giving users less time to react. Guide dogs, while helpful, can be expensive and may fall ill or get injured, making them less reliable. Consequently, these traditional aids are not always efficient. To address these challenges, various research efforts have proposed innovative methods and technologies.

Shaha et al. [11] developed a system using a low latency communication algorithm to inform users about obstacles at various distances through different vibration and buzzing patterns. This system also included a GPS module and an application for real-time tracking. Shahira et al. [12] created a support system that detects obstacles, identifies them, and alerts the user via audio, using an ultrasonic sensor to measure the distance of obstacles. Agrawal et al. [13] proposed a smart stick for blind and visually impaired individuals, integrating components like a sonar transducer, buzzer, GPS module, GSM module, and RF module. This stick detects obstacles in front of the user and provides notifications through a buzzer. O'Brien et al. [14] introduced a cost-effective walking stick system that sounds an alarm when it senses obstacles, using a customized Printed Circuit Board (PCB) with a microcontroller to organize all the sensors and motor. Sahoo et al. [1] proposed a walking stick system that includes a Raspberry Pi controller and an Android app module, notifying the user by vibration or alarm when obstacles or water are detected.

Research on the ESP32 microcontroller and MIT App Inventor is currently limited, as detailed in the following section. Therefore, this study will concentrate on the ESP32 microcontroller as an IoT application, integrated with MIT App Inventor, to detect obstacles and water puddles for visually impaired individuals.

A. ESP32 Microcontroller Module for the Internet of Things (IoT) Applications:

The Internet of Things (IoT) market has seen rapid growth recently, driven by the increasing demand for communication and control across various devices and gadgets. IoT technology significantly influences people's behavior and lifestyles, both professionally and domestically. A key requirement for modern IoT devices is to offer efficient connectivity, ensuring reliable remote communication and data transfer in wireless environments. To further advance IoT technology and broaden its applications, IoT devices must be efficient, cost-effective, and energy-efficient. A small form factor is also crucial; the smaller and lighter the unit, the more versatile its applications. Each IoT-based unit typically includes a microcontroller (µC) and a module for wireless communication (WiFi or Bluetooth), or a combination of both. The detailed structure of the ESP32 system is explained in the below figure.

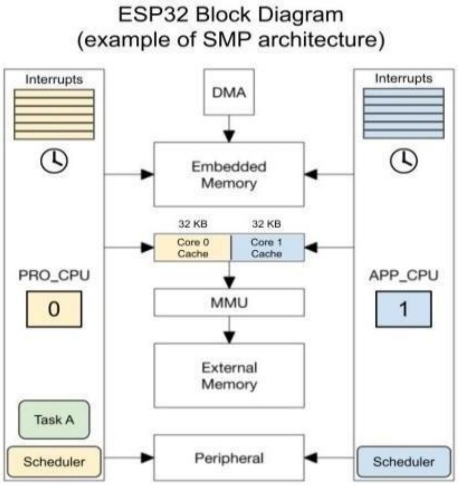

Figure 1: ESP32 System Structure

Maeir et al. [15] highlighted that the ESP32 microcontroller primarily uses the C programming language, making most API libraries available in C as well. Being open source, the ESP32 allows for the development of custom operating systems, with available solutions for programming it in LUA or JavaScript. Its high performance is attributed to its dual-core configuration and extensive operational functionality. The microcontroller process flowchart is depicted in Figure 2 Consequently, the ESP32 is anticipated to play a crucial role in the design of future IoT systems, particularly in the context of this study.

A walking stick can be configured using various techniques and technologies. For example, some systems integrate multiple technologies [16]. Based on existing methods, the developed walking stick can be categorized into three types. The distance calculation is performed using the formula for the time taken for sound to travel to an obstacle and back.

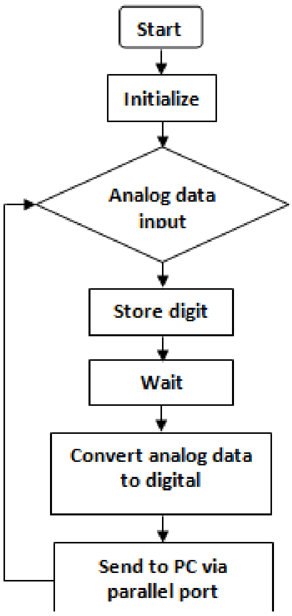

Figure 2: Microcontroller Flowchart

B. Taxonomy of the Reviewed Walking Sticks:

A walking stick is set up according to specific techniques. For instance, some systems are designed using a combination of different technologies [16]. Consequently, based on existing methods, the walking stick that is developed can be divided into three and receiving of the sound is used to calculate the distance using the formula of categories.

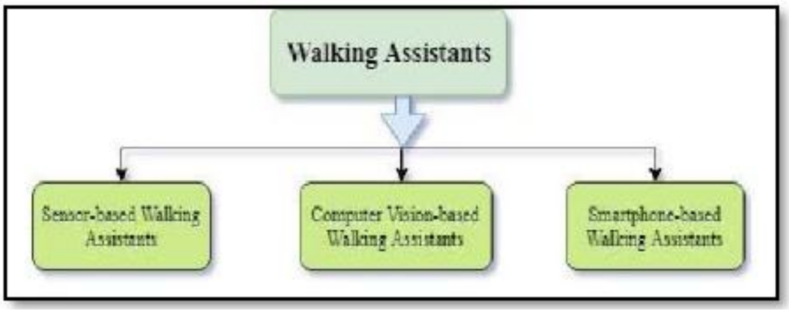

Figure 3: Taxonomy of the reviewed walking assistants for visually impaired persons.

Methodology:

The method to construct the proposed system is divided into three phases: prototype design and development, Android application development using MIT App Inventor, and operation mode and data documentation. An ultrasonic sensor is used for detecting obstacles in front of the user. Another ultrasonic sensor detects holes and uneven surfaces on the ground or road. A PIR motion sensor detects moving objects in front of the user. All sensor data is transmitted to the user's smart phone via a Bluetooth module.

Android Application Development:

The MIT App Inventor is used to develop an app that scans and pairs with the ESP32's Bluetooth module. The app provides speech instructions to notify the user of obstacles, holes, or moving objects. Operation Mode and Data Documentation: The system's operation and data documentation ensure proper functionality and user guidance. The block diagram of the proposed system is depicted in figure.4

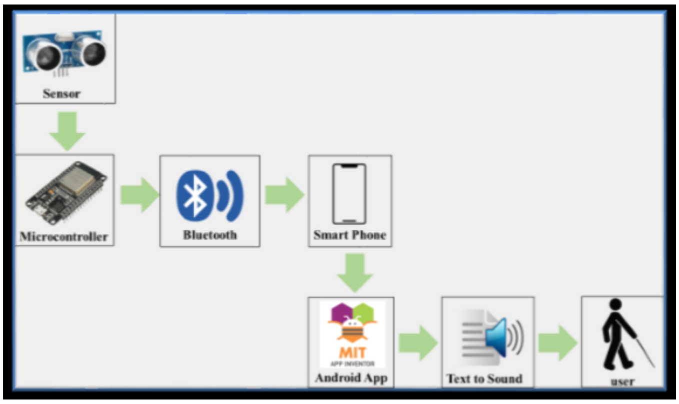

Figure 4: Block diagram of proposed system

A. Prototype Design and Development:

An ultrasonic sensor is a well-known device used to measure the distance of an object using sound waves. It operates by emitting a sound wave at an ultrasonic frequency and waiting for it to bounce back from the object. The time delay between the transmission and reception of the sound wave is used to calculate the distance.

$$\text{Distance} = \frac{(\text{Speed of sound} \times \text{time delay})}{2} \qquad (1)$$

In this study, the HC-SR04 ultrasonic sensor is chosen for the prototype due to its affordability, user- friendly interface, and functionality. Figure 5 illustrates the HC-SR04. It has four pins: Vcc (5V supply), Gnd (Ground), Trig (Trigger), and Echo (Receive). The sensor operates at a 5V DC voltage and has an operating current of 15mA. The ultrasonic sensor functions as a "third eye" for visually impaired individuals. It performs close-range detection of various obstacles and angles, with each detected data point triggering the Virtual Personal Assistant (VPA), such as Google Assistant, to notify the user.

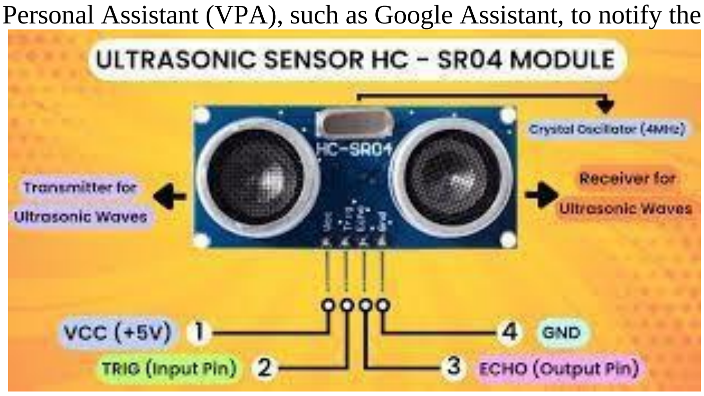

Figure 5: Pins on HC-SR04 ultrasonic sensor

B. Android Applications Development Using MIT App Inventor:

MIT App Inventor is a groundbreaking platform for creating apps using visual, drag-and-drop building blocks. Its intuitive graphical interface is highly user-friendly, allowing even beginners to develop a basic, fully functional app in an hour or less. Figure 6 illustrates the user interface where the MIT App is paired with the Bluetooth device, while figure 7 shows the chain blocks created in the programming platform to communicate with the ESP32's Bluetooth module.

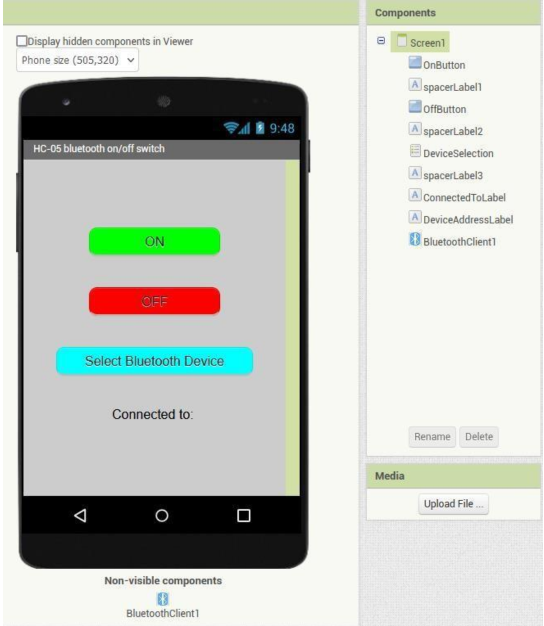

Figure 6: User interface of the Android application shows MIT app inventor designed to scan and pair the Bluetooth device.

C. Operation Mode and Data Documentation:

The majority of cane users prefer mounted canes due to their affordability and comfort. For this project, a mounted cane will be used to align with user preferences. A 3D-printed component box will be attached to the mounted cane to house the components used for prototyping. The design process for the component box will be carried out using Adobe Tinker Cad, and the design will be converted into an STL file for 3D printing with Cura software.

In a survey, 63.2% (24 out of 38) of visually impaired individuals use a white cane with a mounted sensory unit as an assistive tool, without needing any additional devices. Only a small percentage (about 28.9%) prefer handheld devices and use a backpack to carry the computational unit. In this study, a cane is chosen as the assistive tool for visually impaired individuals, rather than standalone handheld or backpack processing units, to meet the specific needs of blind users and the targeted operating environment and functionalities.

During the experimental phase, the final prototype will be tested to gather user feedback. The ultrasonic sensor's functionality will be evaluated at different distances and angles to ensure the phone application provides accurate spoken navigation instructions for visually impaired individuals.

Result and Discussions:

The system was tested by measuring distances of 250cm, 300cm, 400cm, and 450cm to evaluate the functionality of the ultrasonic sensor. Figure 8 shows the distance settings for different obstacles, which will be used as the maximum distance for the final product. Figure 9 illustrates the experimental conditions, including scenarios where an object is in front of a person and when climbing stairs.

Figure 10 provides an example of results obtained from MIT App Inventor, showing conditional statements for different distances. For instance, if the distance is less than 1 meter, the app will execute the command "object ahead." Additionally, the MIT App Inventor script in Figure 10 includes a history log of detected obstacles for recording purposes.

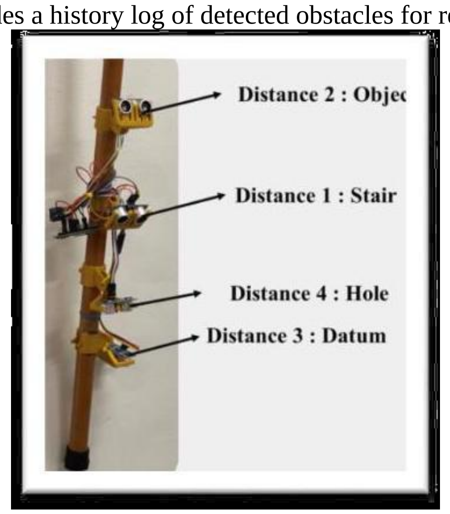

Figure 8: Distance sets on the ultrasonic sensor representing on different obstacle

a) Closer look when a prototype is used to climb up stairs.

b) Experiment on prototype when an object is in front of a visually impaired person

Figure 9: Experiment conducted on prototype in different condition

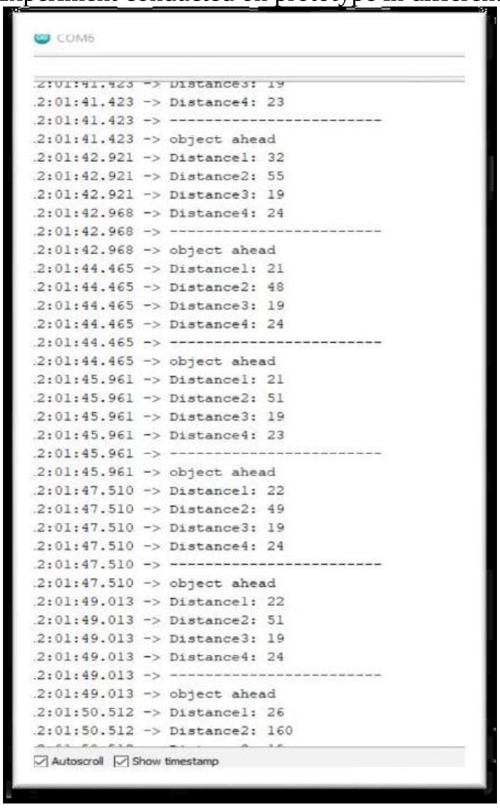

Figure 10: Conditional statement if distance type 1 (stair) and distance type 2 (object) value less than 1m, execute “object ahead”

Conclusion:

This paper presents the successful development of an IoT- based obstacle detection system for visually impaired individuals, incorporating a smart phone module. The system is designed to generate audio alerts to inform users of obstacles in both indoor and outdoor environments. The prototype has been rigorously tested for its detection capabilities. Results indicate that the system can effectively identify obstacles and water puddles within its detection range, achieving an accuracy of approximately 99.59% at 290cm and 99.03% at 490cm. It can also detect angles ranging from 30° to 90° and identify moving objects ahead. Users receive real-time notifications through a mobile app, ensuring their safety. This system aims to provide visually impaired individuals with the independence to navigate safely, ultimately boosting their confidence in unfamiliar environments.

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